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IDENTIFICATION AND ANALYSIS OF STRUCTURAL-TECTONIC FEATURES OF GEOLOGICAL TERRAINS USING LINEAMENT ANALYSIS: EXAMPLES OF GEOMODELLING FOR CANADIAN AND UKRAINIAN SHIELDS

(Представлено членом редакційної колегії д-ром геол. наук, проф. В. А. Михайловим)

Nowadays, rare earth elements (REEs), which belong to the group of rare metals, are considered worldwide to be strategic critical raw materials and are extremely important for the economic development of any country. Various methods and approaches are used for prospecting and exploration of deposits of these critical metals; among which the methods of 3D geological modeling are currently prioritized, which allow a comprehensive analysis of the structural features of potentially promising areas as well as individual deposits. One of the methods used for REE exploration is structural mapping combined with geological terrain analysis, including structural lineament analysis. The latter is considered an important geological tool for identifying the primary and secondary structural and tectonic features of our study areas of investigation.

The objectives of the present research work are: 1) to identify structural lineaments within two studied areas – the Alces Lake area (Northern Saskatchewan, Canadian Shield) and the Western Azov region (Azov block of the Ukrainian Shield) using automated and manual approaches, 2) to compare the results obtained for both areas, and 3) to discuss interpretation/conclusions over the overall suitability of the method for the exploration purposes. In the current research, we conducted the extraction and geospatial analysis of linear features and their tectonic interpretation. During the modeling process, remote sensing and geostatistical methods were used to analyze topographic, geological and geophysical data. As a result, the main structural lineament trends for the two studied areas were identified and structural-tectonic criteria for the formation and localization of deposits of rare earth elements were determined/proposed.

Keywords: geological modeling, spatial modelling, REEs, structural lineament analysis.

Introduction. During Greenfield and Brownfield exploration programs many geological, geophysical, and geochemical exploration methods are used in order to discover new metal deposits. Among these, geophysical methods (including the ground and airborne geophysical techniques) and remote sensing data are routinely used to detect and map the potential ore bodies. Geophysical and topographic data is collected, processed, and analyzed at different scales, thus it can facilitate making discoveries on a regional- to district- to deposit scale. Even though these geophysical methods cannot provide direct detection of REE mineralization, coupled with the 2D/3D modeling they can still give us necessary information on some of the geological/lithological controls, which may lead us to the identification of a structural pathway and/or geochemical trap of the given mineralization.

Geological modeling is a powerful tool for visualization of different geological systems and allows us to better understand a given prospective mineralized area. It can be useful at every stage of exploration of the given deposit and helps us develop efficient geo-metallurgical delineation plans for future exploitation. Such modeling approach that incorporates different types of data such as geophysical, geochemical, remote sensing data etc. is widely used in mineral exploration within a variety of geological and tectonic settings (*Denton et al., 2019*). When we combine and integrate various methods, we can get significant insights into a particular mineral system, which significantly enhances an exploration program for the REE deposits.

In our research, we utilized the lineament analysis method, whereby we mapped the structural lineament features (i.e. interpreted shear zones, fault zones) using both geophysical and topographic data. Such method is used a lot during exploration research (*Kassou et al., 2012; Yeomans et al., 2019; Patra et al., 2013*). The reason for that is that the identified lineament features have often a direct connection to such structural elements as faults, shear zones, folding patterns, and lithological boundaries. Thus, we attempted to decipher the surface/subsurface structures of the two selected areas using remote sensing tools and interpretations of geological features from potential field data. The extracted information was then integrated with and compared to the available tectonic and geological information from each area.

Objective of the study. The main objective of the research in this paper is to map the structural lineament features of the two areas by using automated and manual approaches of the lineament extraction, compare the results obtained for both areas and to make conclusions over the overall suitability of the method for the exploration purposes.

This paper is a part of a larger study (*Poliakovska et al., 2019, 2020; Sykes & Annesley, 2017; Sykes et al., 2020)* that is focused on the study of the Alces Lake area REE-Th-U mineralization (SK, Canada) and its comparison to a similar area within the West Azov block of the Ukrainian Shield. The Alces Lake area may represent the Abyssal pegmatite subclass (*Černý & Ercit, 2005*). This type of pegmatite deposit is rarely related to a granite body (pluton) nearby and is often found within upper-amphibolite- to granulite-facies migmatitic host rocks. Alces Lake is ranked as the highest-grade REE occurrences in Canada (http://www.appiaenergy.ca/). The REEs are hosted in monazites within granitic to residual melt pegmatites, which are associated with biotite-rich (+/- sulfides) paragneisses (*Bell, 2014; Normand, 2010, 2014*). The second tested area, West Azov area of the eastern Ukrainian Shield, is considered a promising target area for REE exploration. Within the West Azov block deposits and occurrences of rare earth elements are associated with the formation of rare metal-rare earth granite pegmatites, confined to the Mesoarchean trough-like structures, but also with rare earth granites and rare earth metasomatites, etc. The most favorable conditions for localization of the REE mineralization are observed to occur within areas with intensively deformed and folded gneissic rocks, that is the structural-metallogenic zones.

Geological Setting – Alces Lake. Alces Lake is located approximately 34 kilometers east of Uranium City, about 28 km north of the Athabasca Basin margin. Alces Lake property is located within the Beaverlodge Domain at the junction of the Beaverlodge, Train, Zemlak, and Ena Domains in the Rae Subprovince. The Beaverlodge and Tran Domains are separated by the S. Louis Fault – a major regional structure striking ENE and dipping steeply SSE (Fig. 1). The Beaverlodge Domain is underlain by Archaean meta-igneous gneisses and Paleoproterozoic meta-sedimentary/meta-igneous gneisses which were highly deformed, metamorphosed, and partially melted during Paleoproterozoic collisional and accretionary events (i.e. during the Arrowsmith (D1, D2), Taltson (D3), and Hudsonian orogenies) (*Ashton at al., 2009; Hoffman, 1988; Regis, 2021*). As a result of those events, abundant granitic and pegmatitic sheets formed throughout the Beaverlodge Domain, in particular within the amphibolite- to granulite-facies Murmac Bay Group metasediments at different structural levels. Within the Beaverlodge Domain, the mineralization is closely associated spatially with the contact between Archean rocks and Paleoproterozoic supracrustal packages composed of quartzite, amphibolite, psammite, psammopelite, and pelite rocks of the Murmac Bay Group (Fig. 2) (*Annesley et al., 2019; Bethune et al., 2013*; *Normand, 2010*).

The Alces Lake REE area is a part of a regional refolded fold structure, within a synformal anticline. The mineralization is located on the eastern limb, close to the hinge of a south-plunging, truncated open fold (*Normand, 2010; Normand, 2014*). The REE mineralized system is composed of Proterozoic late-orogenic to metasomatic massive braided biotite schist, quartzofeldspathic pegmatite augen, and monazite accumulations. All the REEs are fully hosted within monazites and can be found in both the biotite schists and pegmatite augens (*http://www.appiaenergy.ca/; Chandrirgi-Martinez & Pan, 2018*). The monazite mineralization occurs in different habits as isolated grains within 1 to 3 cm thin lenses, as isolated massive clusters up to m's thick, and as pervasive massive clusters of monazite in augenitic (boudinaged) masses along ductile to ductile/brittle to brittle structures.

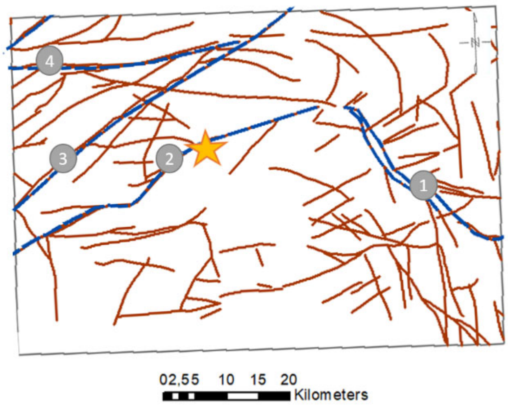

Fig. 1. Selected known faults and shear zones identified for the Alces Lake area within the Beaverlodge domain. Star marks the location of the Alces Lake deposit. The Beaverlodge domain is bounded to the north by the Oldman-Bulyea shear zone (1) – a >70 km-long thrust-sense structure, dipping SW and St. Louis fault (2) and to the west by the Black Bay fault zone (3) – a major Paleoproterozoic, NE-SW-trending crustal-scale fault zone. 4 – Tazin Lake Fault – separates the Ena and Zemlak domains

Lithological units on the Alces Lake property include:

- Archean granitic gneiss.
- Paleoproterozoic metasedimentary gneiss (pelitic-psammopelitic [+/-graphite], quartzite, amphibolite, pyroxenite, diatexite), and feldspathic gneiss.
- Paleoproterozoic syn-to late-anatectic pegmatites.
- Paleoproterozoic late-orogenic to metasomatic biotite schist, pegmatite augen and monazite accumulations (the REE mineralized system) (http://www.appiaenergy.ca/).

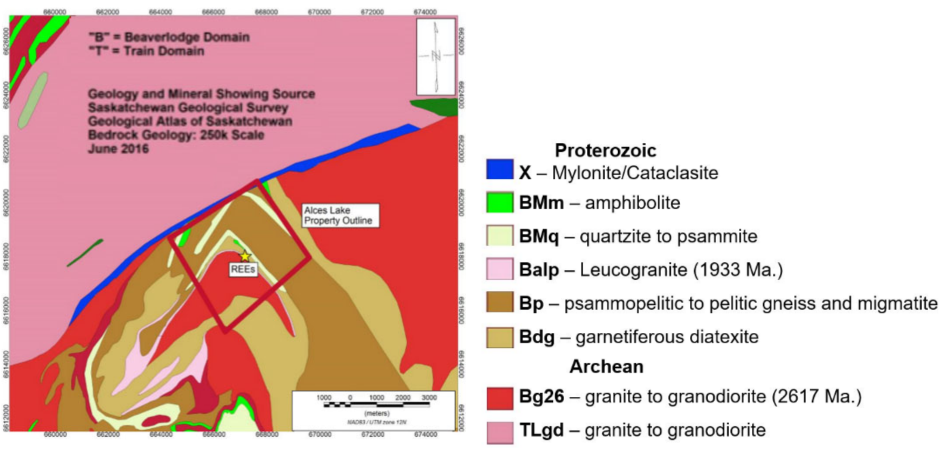

Fig. 2. Geological setting of Alces Lake in the Beaverlodge Domain (modified after Normand 2014 and the Saskatchewan Geological Atlas). Figure is courtesy of Appia Energy Corp. (2021). The property outline is that of the original main outcrop showings. The presnt property is much larger and its dimensions can be found on Appia's website

The authors opine that the mineralized pegmatites have been emplaced within/near the Archean/Paleoproterozoic transition zone under middle crustal P-T conditions and form polyphase anatectic pods/boudins/zones along/near this transition. Emplacement of the pegmatites is interpreted to be deep-seated, structurally controlled along ductile to ductile-brittle to brittle shear zones/faults associated spatially with regional polyphase fold structures (*Poliakovska et al, 2021).*

Geological Setting – West Azov area. The West Azov area is a part of the Azov block within the Ukrainian Shield (Fig. 3). The Ukrainian shield in general has been studied and described by many different scientists, however, there are still some ongoing debates concerning the smaller local areas and the genesis of some REE deposits (*Sukach et al. 2021, Syomka et al., 2010*).

Three main stages of tectonic evolution have been identified in this area: pre-platform (Archean), early platform (Proterozoic), and platform (Paleozoic and Mesocainozoic) stages (*Claesson et al., 2006*).

The Azov megablock underwent a powerful tectonic-magmatic activation in the Proterozoic, leading to the formation of subalkaline and alkaline massifs (granosyenites, syenites, gabbro-syenites, alkaline and nepheline syenites). The megablock is considered by many researchers as a fragment of the Archean granite-greenstone area / craton involved in collisional Paleoproterozoic metamorphism. A distinctive feature of the Azov megablock is a significant intensity and unevenness of metamorphism from epidote-amphibolite to granulite facies, widespread development of alkaline magmatite massifs (*Pokalyuk et al., 2019*). We studied the deposits in pegmatoid granites and quartz-microcline metasomatites, which were formed at the stage of early Proterozoic granitization of the Precambrian regions. Mineralization is usually found localized in metasomatically altered pegmatites, aplites and granites, forming a series of subparallel veins (*Sukach et al., 2021*).

One of the main interests is the Vovchansky tectonic block, which hosts the REE Dibrovo deposit. The Vovchansky tectonic block is characterized by a multilevel folded-domed structure, mainly antiformal. The lower structural level is composed of Paleo-, Mesoarchean plagiogranitoids with xenoliths / inclusions of amphibolite and gneiss bodies. These rocks form mainly dome-shaped antiform structures. Rocks of the upper level overlie the Paleoarchean structural level with a clear angular unconformity.

The upper Archean-Proterozoic level, which fills the interdome synform structures, is represented by metamorphosed amphibolite-granulite facies rocks of volcanic and sedimentary genesis.

The Dibrovo synclinal structure is a 4 by 1.5 km synclinal fold with steeply dipping limbs. It is composed of supracrustal rocks metamorphosed under amphibolite facies conditions; locally granulite to epidote-amphibolite facies. The Dibrovo deposit is located within a complex tectonic junction at the intersection of the Devladivska and diagonal fault zones with respective north-eastern and south-eastern structural trends. The ore bodies are represented by a system of lenticular veins/bodies of microclinized quartzites and dynamo-metosomatically altered pegmatites, oriented subparallel with the strike of the host Paleoproterozoic metasedimentary rocks.

Mineralization at the Dibrovo deposit marks the unconformity surface between the Archaean (Archaean plagiogranitoid basement) and the Paleoproterozoic (metamorphosed sedimentary, volcanogenic-sedimentary complexes).

Rare earth, Th, and U are mostly found in monazite, but also in zircon, uranininite, and brannerite. In some large fragments of plagioclase-microcline granites in quartzites and their small intervals in the core, where the content of monazite reaches 15–18 %. The mineralization was probably formed as a result of the ultrametamorphic metasomatic processes that accompanied the intrusion of aplite pegmatoid granite bodies into the meta-terrigenous rocks and provoked remobilization, redistribution and enrichment of the primary mineralization.

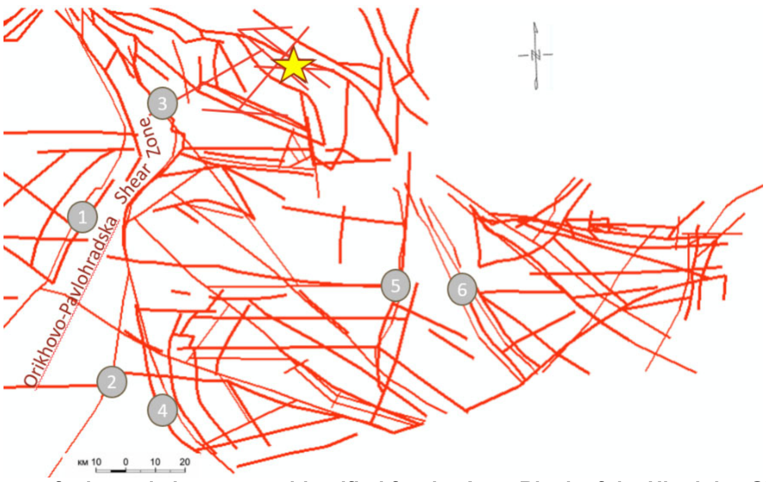

Fig. 3. Known faults and shear zones identified for the Azov Block of the Ukrainian Shield. Star marks the location of the Dibrovo deposit. Orikhovo-Pavlohradska Shear Zone – located between the Azov and Middle Dnieper megablocks (separated by deep faults: 1 – Orikhivsko-Pavlohradskyi fault, 2 – Zakhidnopryazovskyi fault, 3 – Pavlohradskyi fault, 4 – Korsatskyi fault). The width of the zone decreases from south to north from 50 to 7 km. 5 – Tsentralnopryazovskyi fault and 6 – Maloianisolskyi fault – zones of deep faults, that separate the Azov megablock into three blocks – West, Central and East

Input Data. A geological database was created with the following datasets:

1) *Surface topography*:

The surface topography was modeled using the SRTM data (Shuttle Radar Topography Mission – Spatial Resolution 30 meters), DEM data (Digital Elevation Model) and Landsat 8 (Date Acquired – 17.06.20, Spatial Resolution 30 meters) images.

2) *Geological maps, figures, cross-sections, and the database of known faults and shear zones* within the two study areas:

The reports, maps, figures and cross-sections from previous existing investigations of the areas were digitized; valuable information for the current research was extracted.

3) *Geophysical data*:

The data used in the current study for the Alces Lake area was retrieved from the Saskatchewan Geological Survey public domain database (district-scale data) and provided by the Appia Rare Earths & Uranium Corp. (*Appia Rare…, n.d.*). The geophysical datasets were provided by Appia Energy Corp and conducted by the MWH Geo-Surveys Ltd and Geotech Ltd in June 2019 and May 2016, respectively.

The geophysical data for the Ukrainian shield was collected form the public domains or retrieved from the geological reports (*Pigulevskiy, 2012; Svistun and Pigulevskiy, 2021).*

GeoModeling Methodology – Processing and Interpretation of Satellite imagery and Geophysical data. To characterize the studied terranes, gravity, magnetic, and remote sensing data were analyzed. Geophysical methods are widely used in geology, especially during the exploration programs. They help mineral exploration geoscientists understand the geology of the subsurface and model the crustal blocks at different scales. High-resolution geophysical data enables a detailed mapping of the lithological units and geological structures of an area of investigation at a district- to local- to deposit-scale, which can lead to better results in Greenfield to Brownfield exploration programs (*Denton et al.,2020*). Nowadays, such potential field data are utilized to detect among other the iron oxide–copper–gold mineralization, massive sulfides, and structural features such as faults and foldings and in general are widely used for geologic mapping (*Patra et al., 2013*). In this study, we utilized gravity and magnetic survey data and their derivatives. Data was imported into the Geosoft Oasis montaj software package for further processing. Based on study of the 1st vertical derivative, tilt derivative, and total horizontal gradient images we were able to decipher detailed structural fabric of both areas (the magnetic intensity values were first reduced to magnetic pole before applying other filters). Such derivatives are great tools for delineating both deep as well as shallow structures, depending on the enhancement filter used.

Satellite images and aerial photographs are also extremely useful for structural and lithological discrimination (*Patra et al., 2013*). In order to extract the lineaments several steps are required, starting with the pre-processing of these images, followed by the lineament extraction and further spatial analysis.

Image filtering and enhancements are utilized during the image processing stages, because those operations are able to highlight the edges or other linear features, at the same time improving the accuracy (*Ahmadi & Pekkan, 2021*). Thus, various data enhancement techniques were used to selectively improve the signal of interest and allowed geological structures to be seen and mapped considerably more detailed than using the 'raw' data. Different filters and enhancements were applied to the 'raw' images (Fig. 4) and data, which at the end allowed us to perform the lineament feature analysis using both manual and automatic approaches.

The following image enhancements were used for the geophysical grids: RTP, 1VD, Tilt Derivative, Total Horizontal Gradient etc. (Fig. 5). As for the satellite images, there were utilized various image processing filters, such as Gradient S, N, W, E, NE, NW, Laplacian filters etc. The analysis was performed using the ArcGIS 10.4 (Image Analysis tab) and Geosoft Oasis Montaj (2D filtering tools) software packages.

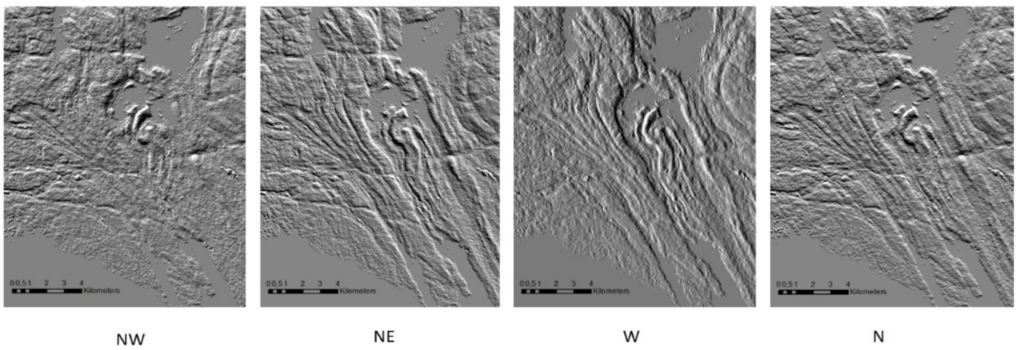

Fig. 4. Example of the remote sensing image processing and enhancement – Gradient NE, NW, W, E filters applied to the DEM image (Beaverlodge domain, Northerm Sakatchewan, Canada)

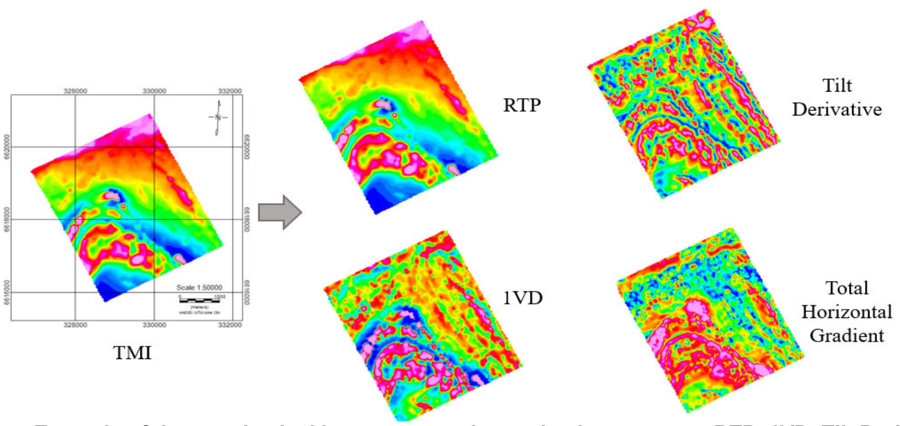

Fig. 5. Example of the geophysical image processing and enhancement – RTP, 1VD, Tilt Derivative, Total Horizontal Gradient filters applied to the TMI image (Beaverlodge domain, Northerm Sakatchewan, Canada)

Lineament analysis. Lineaments (linear features) are considered as curvilinear to straight landforms that are widely distributed across the Earth's surface. They can be controlled by both geological structures (shear zones, lithological boundaries, faults, discontinuities, folds, etc.) and man-made or geomorphological features. The spatial statistical information such as density, length, and orientation of lineaments reflect rock mass fracture patterns and provides valuable information related to hazard assessment, geological structures, tectonics, and natural resource availability. In the current research we carried out lineament analysis using both manual visual identification method and automatic extraction approach with the suitable software. Manual lineament extraction is performed by visual interpretation of human operators and is well suited for spatial assessment; the extraction is conducted using an image enhancement process e.g., directional filtering, band ratio, transformation, visual interpretation, and manual digitization of the lineaments. On the other hand, automated lineament extraction is performed using computer-assisted software. The automated processing includes enhancement, filtering, edge detection, and finally, lineament extraction. The identification of lineaments using the automatic technique is considered more efficient and much faster method than the manual one. However, automatically extracted lineaments tend to contain lineaments derived from other sources besides geological structures, such as railway, power, and fence lines (*Radaideh et al., 2016*).

One of the tasks of this study was to establish a suitable methodology for automatic/digital and manual lineament analysis of potential field geophysical data sets combined with the aerial photography data for further structural interpretation of two selected study areas – i.e., within the Canadian (Alces Lake area) and Ukrainian (West Azov area) Shields. Consequently, we have tested several methods, compared the obtained results from both manual and automated approaches between each other and with the known geological structures.

During the analysis we utilized mainly two types of data to extract the lineaments in both manual and automated approaches – satellite images or aerial photographs and geophysical gravity and magnetic survey data. A number of geomodelling software packages were used for the analysis: Geosoft Oasis Montaj, ArcGIS, and Geoscience ANALYST Pro. Remote sensing and GIS techniques were applied during the process of analyzing and interpreting the geophysical and topography data.

The workflow (Fig. 6) used in this study is composed of four main steps:

1) Selection of the most suitable data for analysis, – e.g. SRTM/DEM/Landsat images, various geophysical data.

2) Potential field geophysical data and aerial photography data processing and enhancements.

3) Lineament extraction by using the manual and automated approaches and their further comparison. Several software packages were used such as ArcGIS and Geoscience ANALYST Pro.

4) Comparison of the final map with available geological and tectonic maps of the area and Geospatial analysis (density, direction, intersection length, and orientation analysis) using the ArcGIS software tools. This way it was possible to evaluate the results obtained with both methods.

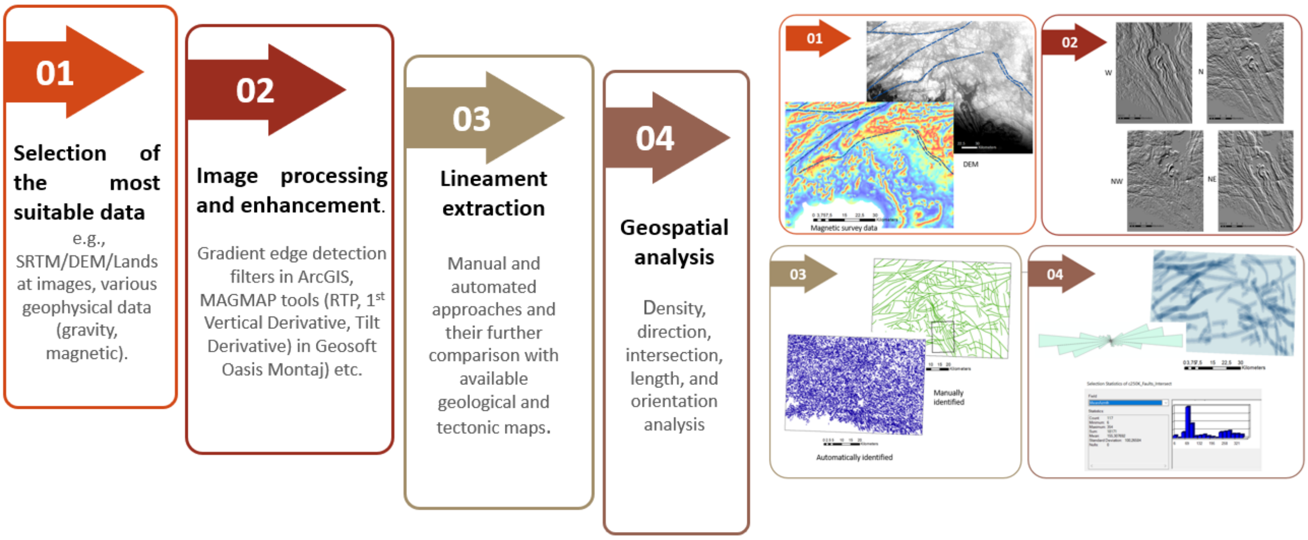

Fig. 6. Proposed lineament analysis workflow

Results and Discussion. Today, rare earth elements, members of the rare metals group, are viewed worldwide as strategic critical raw materials, and are extremely important for the economic development of any country. These elements include the entire range of lanthanides, as well as yttrium and scandium. They are used in the production of high-power magnets, catalysts, high-precision optics, and electronics, among other products.

The use and need for these elements will continue to grow in the future, as they play a key role in achieving the goals of sustainable development. Therefore, discovering deposits of these critical raw materials come to the forefront of today's exploration challenges, where understanding the mineral systems of the rare metals is an essential part of any successful exploration program (*Verplanck, Hitzman, 2016*).

In this paper we presented the lineament analysis and image processing techniques to help generate maps that would show/highlight the areas of geological structural complexity derived from geophysical data and various satellite images. Exploration programs often rely on and are based on combined geological/geophysical/geochemical information, and our resulting lineament analysis maps could provide a significant contribution to the exploration decision-making process. Thus, the preliminary lineament analysis was conducted for the two study areas – Alces Lake area and West Azov area using both topographic (SRTM, DEM, Landsat 8) and geophysical data (derivatives of magnetic and gravity survey data). This was carried out by combining various image analysis processing and enhancement techniques.

Mineral deposits of both study areas – Alces Lake within the Beaverlodge Domain of northern Saskatchewan (Canada) and West Azov region within the Azov Block in Ukraine have a complex genesis, related to the Paleoproterozoic tectonic events that highly deformed and metamorphosed the primarily meta-sedimentary (and meta-igneous) Archean/Paleoproterozoic rocks (table 1). As a result, abundant granitic and pegmatitic sheets were formed throughout the Beaverlodge Domain and the Azov Block. Mineralization of both Precambrian areas occurs near the tectonized unconformity surface between the Archaean basements rocks and the Paleoproterozoic metamorphosed meta-sedimentary/meta-igneous rocks. It is suggested by the authors that the mineralization could have formed as a result of crustal thickening, associated with mafic magma underplating (evidence from abundant mafic dykes/sheets in the Alces Lake area), lower crustal melting, and subsequent decompression and partial melt migration along reactivated shear/fault zones (*Poliakovska et al., 2021).*

Table 1

Comparison between the Alces Lake and Dibrovo REE-Th-U mineralization

Comparison parameter	Alces Lake (Canadian Shield)	Dibrovo (Ukrainian Shield)
Belonging to the tectonic-metamorphic type of Precambrian blocks of the earth's crust (Ukrainian classification)		Granulite-greenstone type or plagiogranite-greenstone type
Degree of regional metamorphism of host rocks	Amphibolite, granulite	Mainly amphibolite, locally granulite and epidote-amphibolite
Tectonic-stratigraphic control	It is confined to the tectonic zone of contact between Archean and Paleoproterozoic complexes, mainly within Paleoproterozoic deposits.	It is confined to the zone of contact between the Archean plagiogranitoid basement and the Paleoproterozoic folded cover. Localization in Paleoproterozoic metasedimentary complexes near the zone of contact with the Archean basement.
Intensity of dynamometamorphism	High	High
Intensity of metasomatism	High	High
Characteristics of metasomatism	Alkaline (potassium-sodium)	Alkaline (potassium-sodium)
Ore bodies	Pegmatoids	Quartzites (metaterrigenous or secondary), Pegmatoids
Host rocks	Paleoproterozoic gneisses, schists	Paleoproterozoic quartzites and high alumina schists
The main ore mineral	Monazite	Monazite
Monazite contents in ore bodies	Up to 85 modal %	Up to 18 modal %
Age of mineralization	1950 to 1750 Ma ????	Productive TR-U-Th mineralization was formed in the Paleoproterozoic stage 1.9–2.2 billion years ago. It was generated by hydrothermal-metasomatic processes that accompanied the penetration of the final magmatic phases, probably of the Saltychan complex, and were represented by granites of the Dibrovo type

In our research study, both automatic and manual methods (Fig. 7) were able to correctly identify some geological structures within the areas of investigation with different degrees of reliability and accuracy. For the manually identified lineament features within the Alces Lake area, the percentage of lineaments that represent the known geological structure out of all the manually identified linear features was 36,9 %, whereas this number for the automatically identified linear features for the same area was 19,8 % (Note for both analyses, a tolerance limit of 250 m was applied).

As for the orientation analysis, both methods could successfully identify the main trends. The main structural elements and associate mineralization are related mainly to the following lineament features: 1) NNW-SSE and E-W (340 and 060 to 090) – oriented structural elements within the Alces Lake area and 2) NW-SE, E-W and NNE (340, 090 and 045) – structural elements within the West Azov area, which can be tracked at different degrees of uncertainty using lineament analysis.

However, it is recommended by authors to utilize the combined manual and automated approach, to achieve the most reliable results. The output is also highly dependent on the area of study. Within the Beaverlodge Domain, the overall close similarity between the lineament trends, present-day drainage system, and subsurface features is a reflection of a highly glaciated terrain with abundant outcrops separated by a very thin glacial cover; suggesting that the development of the present landforms is highly controlled by subsurface basement structures and their reactivation during glacial rebound. This is in sharp contrast to the ones within the West Azov area of the Ukrainian Shield, in which less than 10 % of the identified lineament features corresponded to the deep subsurface structural elements.

The spatial statistical analysis, especially the density one can serve as a good proxy for the structural complexity of the areas, which is an important targeting parameter for mineral exploration. This way we can identify major intersection zones of possible fault dilation with associated fluid and heat flow, where structural geochemical traps are located for mineralizing fluids (melts) and thus providing some new insight to the REE-Th-U mineral systems of the two shield areas. The resultant interpretive maps can show these regions of greatest structural complexity, which then can be used to infer potential targets and to improve the manual or GIS-based perspective (prospectivity) analysis.

Conclusions. In this study we show the results of combined remote sensing and GIS methods in order to attempt to interpret the complex Precambrian shield areas. The various image processing techniques coupled with the lineament extraction methods allow us to study the large areas. They can be an essential integrated component for understanding the tectonics of the area of interest. The lineament analysis has proven its effectiveness in many branches of geological studies and is widely used during mineral and petroleum exploration programs, groundwater surveys, and natural hazard assessment studies.

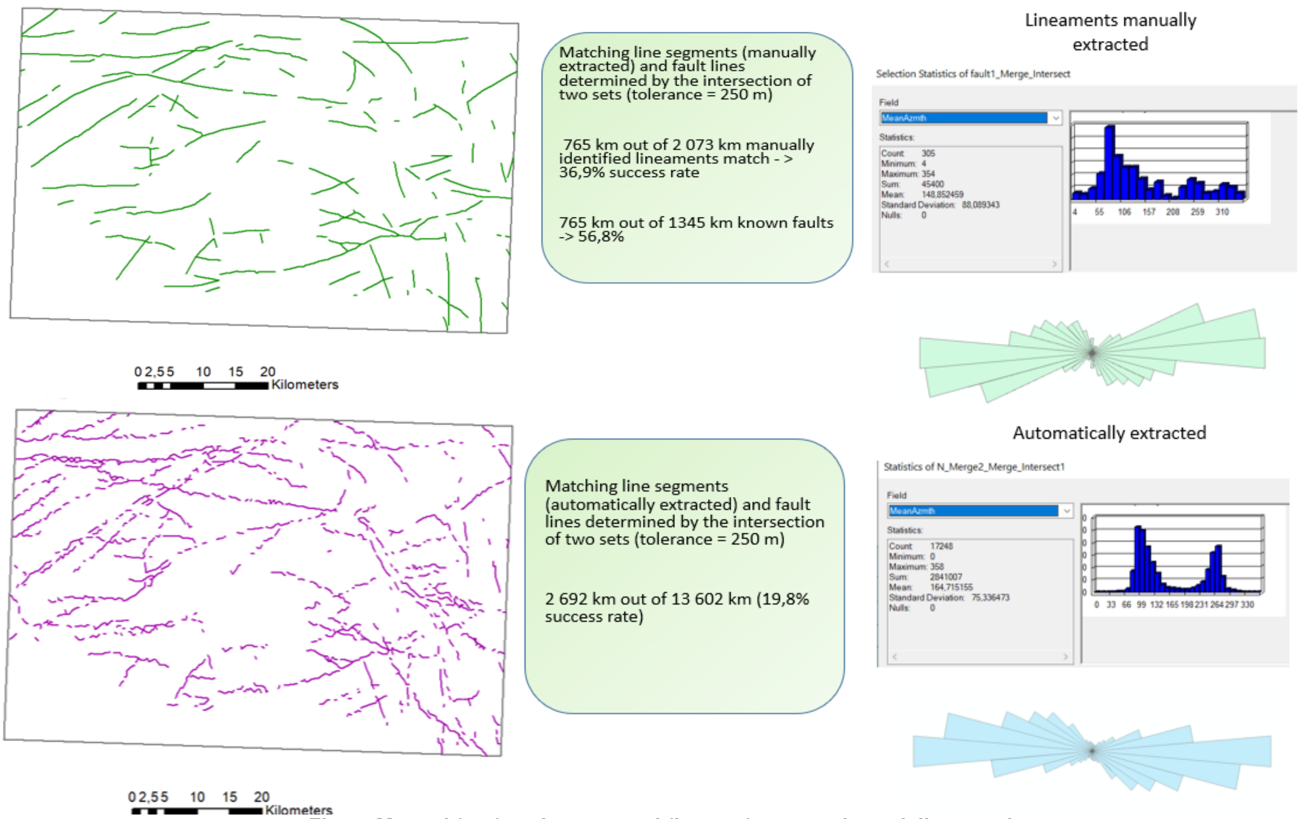

Fig. 7. Manual (top) and automated (bottom) approach modeling results

This paper shows the results of the analysis of two study areas, within the Canadian and Ukrainian Shields, using the automated and manual lineament extraction approaches. We utilized various enhanced and filtered potential field and remote sensing data. Consequently, we were able to identify the prevailing trends in the distribution of structural elements within both study areas. Those are respectively: 1) NNW-SSE (~340) and E-W (060–090) – oriented structural elements within the Alces Lake area and 2) NW-SE, E-W and NNE (340, 090 and 045) – ones within the West Azov area. However, since the geological structures are very much less exposed within the West Azov area (as a result of much thicker cover) the method described in this paper couldn't reveal all of them. Thus, it is concluded that the development of the present-day landscape and drainage systems within the Alces Lake area, in contrast to the West Azov area, was highly controlled or influenced by the outcropping and subsurface geological structures. Therefore, the lineament analysis method can with different levels of accuracy, depending on the characteristics of the studied terrain, give us new insights into the host mineral system and thus facilitate future discoveries.

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ІДЕНТИФІКАЦІЯ ТА АНАЛІЗ СТРУКТУРНО-ТЕКТОНІЧНИХ ОСОБЛИВОСТЕЙ ТЕРИТОРІЇ НА ОСНОВІ ЛІНЕАМЕНТНОГО АНАЛІЗУ: ПРИКЛАДИ ГЕОМОДЕЛЮВАННЯ ДЛЯ ТЕРИТОРІЇ КАНАДСЬКОГО ТА УКРАЇНСЬКОГО ЩИТІВ

На сьогоднішній день рідкісноземельні елементи, що входять до групи рідкісних металів, розглядаються у світі як стратегічна критична сировина і є надзвичайно важливими для економічного розвитку будь-якої країни. Для пошуків та розвідки родовищ цих елементів використовуються різні методи та підходи, серед яких пріоритетне значення мають методи геологічного моделювання, які дозволяють комплексно проаналізувати особливості будови як потенційно перспективних територій, так і окремих родовищ. Одними з методів геомоделювання, що використовуються для пошуків і розвідки родовищ рідкісноземельних елементів, є геолого-структурне картування та лінеаментний аналіз. Це важливі геологічні інструменти для виявлення структурно-тектонічних особливостей території досліджень.

Мета пропонованої роботи – виявити лінеаменти в межах двох досліджених територій – району Альсез Лейк (Північний Саскачеван, Канадський щит) і Західного Приазов'я (Азовський блок Українського щита) – з використанням автоматизованого і ручного підходів, порівняти отримані результати і надати рекомендації щодо можливостей використання цього методу як складової пошуків і розвідки родовищ рідкісноземельних елементів. У цьому дослідженні було виконано ідентифікацію та геопросторовий аналіз лінеаментів із такою тектонічною інтерпретацією. У процесі моделювання для аналізу топографічних і геолого-геофізичних даних було використано методи дистанційного зондування та геостатистики. У результаті було виявлено основні структурні тренди для двох досліджуваних районів та визначено структурно-тектонічні критерії формування і локалізації родовищ рідкісноземельних елементів у їхніх межах.

Ключові слова: геологічне моделювання, просторове моделювання, рідкісноземельні елементи, структурний лінеаментний аналіз.